Section 7.3 (Endcap Region) of Pixel Paper

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7 Mechanical Systems

7.1 Overview

7.2 Barrel Region

7.3 Endcap Region [Version of November 23, 2007]

The active elements of the pixel detector in the two endcap regions are disk sectors, each supporting six modules (three on each side). Eight disk sectors are supported on a disk support ring, forming a disk. There are three disks in each of the two endcaps. The disks in the endcaps are rigidly held by a support frame constructed from carbon composites. This section will describe the construction, survey and testing of the disk sectors (7.3.1), disks (7.3.2) and endcaps (7.3.3).

7.3.1 Disk Sectors

7.3.1.1 Construction

The local support structures (with integrated cooling) for the modules in the endcap region are called disk sectors. The sectors are roughly trapezoidal in shape, and consist of two thin carbon composite sheets with a rectangular aluminum cooling tube and carbon foam in between the sheets. The cooling tube is bent into a W-like shape to fit within the sector, and makes contact with the carbon composite sheets with a compliant, thermally conducting adhesive. Each cooling circuit in the disk region serves two sectors.

[Text here from Gil on the physical construction of the sectors.]

Three modules are mounted on each side of the sector, with the long dimension of the module in the radial direction. The three modules on the back of the sector are rotated 7.5 degrees with respect to the modules on the front side, thus providing full overlapping azimuthal coverage. Figure 1 shows three modules mounted on the front side of a sector.

The modules are glued to the sectors with Dow Corning silicone SE4445. Nylon filaments of 110 μm diameter are used to control the silicone thickness. During the gluing operation the position of survey targets in the corners of each module are viewed with an optical SmartScope, to ensure that the modules are placed in the correct positions on the disk sectors. The modules are positioned and glued on each sector with a precision of 2 μm in the plane of the module and about 10 μm perpendicular to the module plane.

7.3.1.2 Sector Survey

After the modules are glued to the carbon surface of the disk sectors, the sector is again mounted on the table of an optical SmartScope. The SmartScope very precisely measures X,Y coordinates (in the plane of the sector) by measuring the position of the table, and measures Z coordinates (perpendicular to the sector) with optical focusing. The SmartScope is used to measure the X,Y position of survey targets at the 4 corners of modules mounted on a disk sector, and these measurements are used to determine the position and orientation of the module in the plane of the sector. The SmartScope also measures 32 X,Y,Z points on the top side of modules mounted on a sector (16 along one long edge, 16 along the other long edge) in the vicinity of the first and last chip ID pads of each front-end chip, and these measurements are used to determine the position and

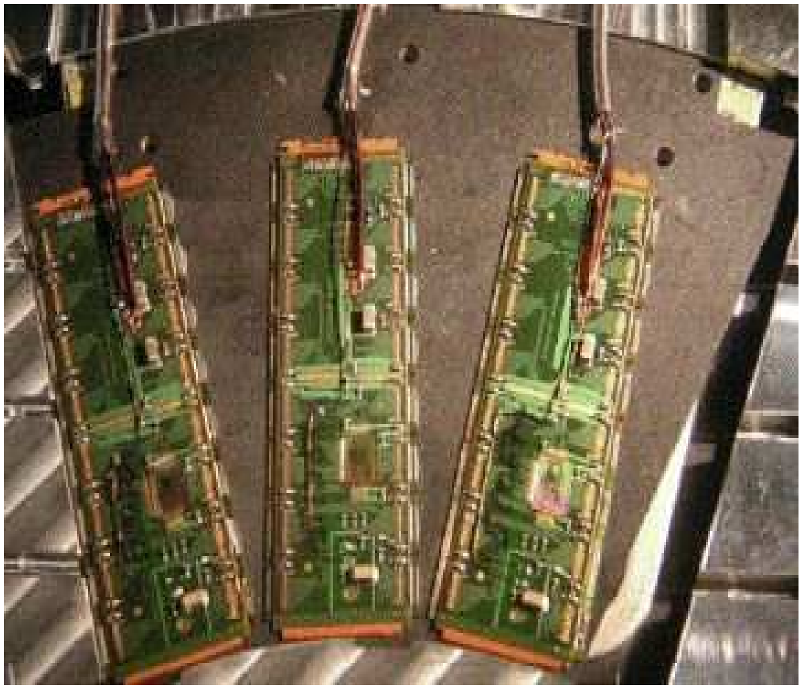

Figure 1: Three endcap pixel modules mounted on the front side of a sector.

rotations of the module out of the sector plane. The pixel module is treated as a flat rigid plane, as the module distortions (such as bow) are very small.

From the above SmartScope measurements the alignment parameters of each module were calculated in the local module reference frame. The module alignment parameters are those 6 parameters used to describe a flat plane: X, Y, Z, Φ_x, Φ_y, Φ_z. X is the coordinate across the short width of the module, and Y is the coordinate along the long length of the module. In the local module reference frame the module alignment parameters are the displacements of the module from its nominal position (i.e. the difference from nominal). The X,Y,Φ_z alignment parameters calculated from the sector surveys are not the final survey alignment parameters, as they do not include the effect of the placement of the sector on the disk ring. Details about the calculation of the module alignment parameters are given in [1].

In Figure 2 are the distributions of the X,Y,Φ_z module alignment parameters calculated from the sector surveys (treating all the modules as A Disk modules, which means plotting the negative of the actual X and Φ_z values for the C Disk modules), and in Table 1 are the means and sigmas of the Gaussian fits to these distributions. One sees several features:

- The mean of the X alignment parameter distribution is different for front and back modules: -2.8 μm for front modules, and $+2.8$ μm for back modules. This is due to a small systematic offset when the modules were mounted on the sectors. The opposite sign occurs when converting the survey measurements to the same coordinate system.

- The average sigma for the X and Y alignment parameter distributions is 2.0 μm, and the sigma for the Φ_z alignment parameter distribution is 0.064 mrad. These resolutions include both the placement accuracy and the measurement precision, and thus represent upper limits on the placement accuracy. These small values show that the modules have been placed on the sectors with excellent accuracy of better than 2 μm.

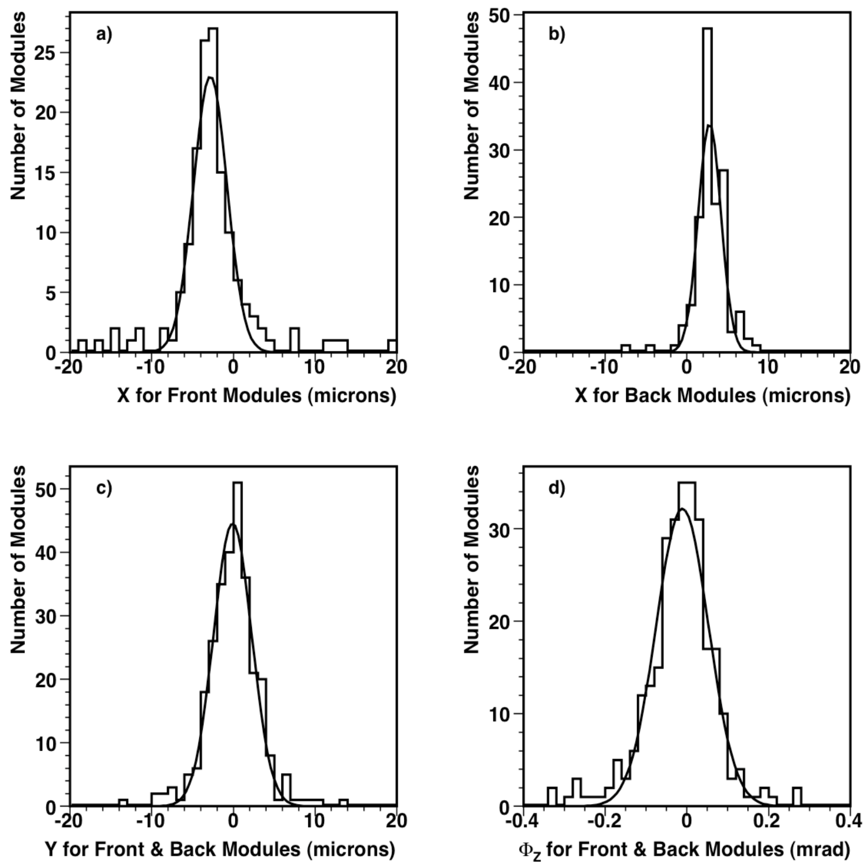

Figure 2: X,Y,Φ_z alignment parameters calculated from the sector surveys.

7.3.1.3 Sector Testing

Electrical and thermal tests are performed on the modules after they are glued onto the sectors. The goal is to check any degradation of module performances (early break-down, increased noise, bump failures, etc.) caused by thermal or mechanical stresses from loading. Another aim is to rank the sectors for disk loading so that the sectors with the least number of bad pixels can be loaded onto the innermost disks. The tests performed on each module are part of the full quality control procedure of the ATLAS Pixel Detector and more details are given in [2]. The electrical sector testing sequence consists of the following three sets of basic monitoring scans:

	Mean	Sigma
X for Front Modules	-2.8 ± 0.2 μm	2.1 ± 0.2 μm
X for Back Modules	$+2.8 \pm 0.1$ μm	1.4 ± 0.1 μm
Y for Front and Back Modules	-0.1 ± 0.1 μm	2.3 ± 0.1 μm
Φ_z for Front and Back Modules	-0.011 ± 0.004 mrad	0.064 ± 0.004 mrad

Table 1: Results of the Gaussian fits to the sector survey distributions in Figure 2.

- LOAD test: This test is performed immediately after sector loading at room temperature. The test includes I-V, digital, analog threshold, crosstalk and source scans. Data from this test are compared to the single module BURN test (a test performed under similar conditions before the module was loaded on the sector) to observe any changes due to sector loading. All six modules on the sector are tested individually before proceeding to the next test.

- INBURN test: During this test the sector is cold soaked for a period of about 12 hours at -30°C with the power off. It is then thermal cycled between -20°C and 20°C (T_{NTC}=-16 to 25°C) with the power on. The dwell time at each endpoint is 1 hour and the entire test consists of 14 cycles with about 3.5 hours per cycle. Digital and analog threshold scans are run throughout the burn-in, while monitoring T_{NTC} and digital/analog voltages and currents.

- STAVE test: The full electrical characterization is performed after burn-in at operating temperature (T_{NTC}= -5 to -10°C) for a fully configured module. The test includes all LOAD scans as well as MonLeak, in-time threshold and GDAC scans. Data from this test are compared to the single module FLEX test to detect any changes due to sector loading or sector burn-in, and serve as the basis for sector ranking.

Electrical testing and burn-in were performed using one setup. The details of the technical description are given in [3]. The standard module testing hardware chain was used: a PC computer with VME and GPIB interfaces (control cards), ATLAS Pixel TurboDAQ software, a VME crate with a custom board (ATLAS Turbo Pixel Low Level card), an external custom board (ATLAS Turbo Pixel Control Card), GPIB controlled off-the-shelf power supplies, and a LBNL custom designed SURF board with module(s) attached to it. Two surf boards [4] were used to connect all six modules at once. The sector was cooled using an inert flourocarbon C_6F_{14} running in a secondary loop connected to the sector cooling pipes. Dynalene (HC-50) was used in the primary loop and was cooled using a chiller. The two loops made thermal contact inside a coiled heat exchanger.

The following measurements made during the electrical tests described above were used to rank the sectors: bias current at 150 V, number of bad pixels in digital scans, number of bad pixels in analog threshold scans, number of bad pixels in crosstalk scans, number of bad pixels in in-time scans, number of bad pixels due to bump discontinuity, number of dead or masked pixels measured during source scans, threshold dispersion, and average noise.

The cuts for bad pixels are defined according to guidelines from the ATLAS Pixel Detector collaboration. The above quantities were entered into the Pixel DataBase to maintain a comlete record of the production sequence and allow the possiblity of tracing any eventual problems. Sector evaluation also considered results from the alignment survey and thermal performance measurements during the electrical tests.

The total number of bad pixels in each of the endcaps can be estimated using the results of the STAVE test performed at the sector level since this is the last, full electrical characterization performed on the modules at operating temperature. It is also the last source scan where bump discontinuity can be accurately measured. Table 2 shows the total number of bad pixels for each of the endcaps, classified by failure. Bad pixels are not double counted: if a pixel is bad digitally, it is not counted as analog bad or source bad.

EndCap	SOURCE	MASK	DIG	ANA	DISC	XTALK	INTIME	TOTAL	%
A	5497	373	5816	471	2559	171	2671	17531	0.26
C	4221	360	52	594	636	127	3131	9036	0.14

Table 2: *Number of bad pixels for each endcap, classified by failure. Results are taken from the STAVE test and later connectivity tests.*

7.3.2 Endcap Disks

7.3.2.1 Construction

Eight disk sectors are mounted on a 312 mm diameter carbon composite disk support ring, forming a disk. There are three disks in each of the two Endcaps. Each disk has 48 modules, for a total of 288 modules. The radius of the module centers is approximately 119 mm. The inner radius of the active area of the pixel modules is approximately 89 mm. Figure 3 shows one of the completed disks.

7.3.2.2 Disk Survey

After the disk sectors are mounted on the disk ring, the X,Y positions of the survey targets at the four corners of each front module are again precisely measured with the SmartScope, and are used to determine the final survey position and orientation of the front modules on the disk with a precision of a micron. The back modules are not surveyed after mounting the sectors on the disk, but the measurements done after mounting the modules on the sectors are used to calculate the positions of the back modules on the disks with a precision of about 5 microns.

The final X,Y,Φ_z alignment parameters of the modules were calculated from the disk survey SmartScope measurements in a manner similar to the way they were previously

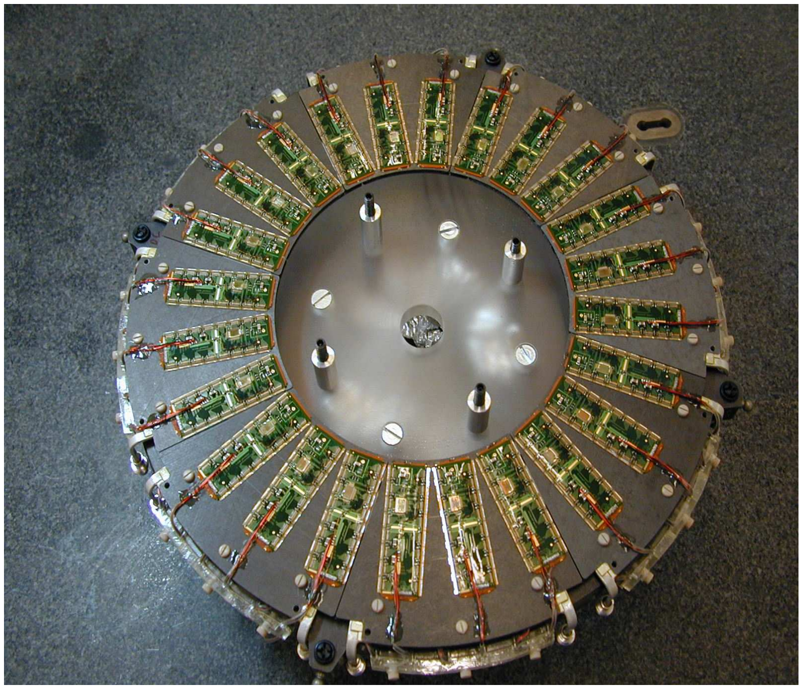

Figure 3: Eight sectors assembled into a disk.

calculated for the sector survey measurements. These final X,Y,Φ_z alignment parameters are the displacements from nominal due to both the placement of the modules on the sector and the placement of the sectors on the disk ring.

In Figure 4 are the distributions of the final X,Y,Φ_z module alignment parameters calculated from the disk surveys (treating all the modules as A Disk modules, which means plotting the negative of the actual X and Φ_z values for the C Disk modules), and in Table 3 are the means and sigmas of the Gaussian fits to these distributions. One sees several features:

- The average sigma for the X and Y alignment parameter distributions is 12 μm, and the sigma for the Φ_z alignment parameter distribution is 0.130 mrad. These values include both the placement of the modules on the sector and the placement of the sectors on the disk ring. Recall from the sector survey results (which only include the placement of the modules on the sector), that the average sigma for X and Y was 2.0 μm, and the sigma for Φ_z was 0.064 mrad. Thus we see a much larger variation in the module position due to the sectors being placed on the disk ring than due to the modules being placed on the sector.

- The mean of the Y alignment parameter distribution is 35 μm. The local module Y direction is the radial direction in the disk. The reason that the Y alignment parameter is so large is mostly because the average radius of the mounting holes in the disk rings is larger than the nominal value of 156 mm. From independent disk ring measurements, the radius appears to be roughly 25 μm larger than nominal. This accounts for the major part of the 35 μm.

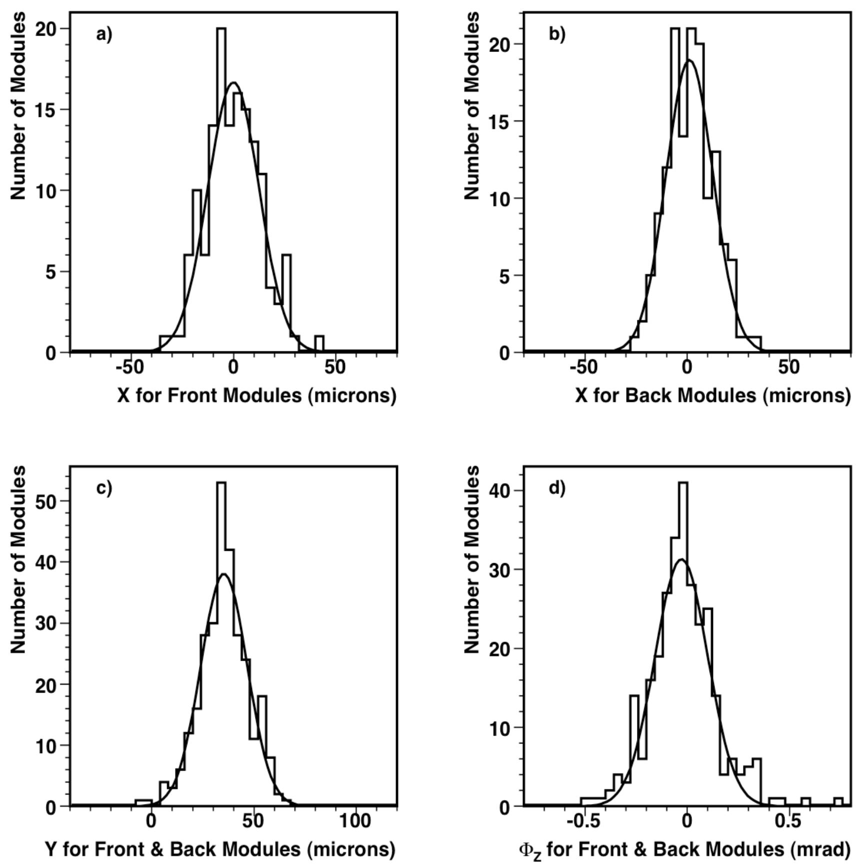

Figure 4: Final X,Y,Φ_z alignment parameters calculated from the disk surveys.

7.3.2.3 Disk Testing

After the sectors were mounted on a disk ring, a continuity test was performed on the modules. Its purpose was to quickly check that the delicate module circuitry survived the mounting operation and any sector or disk handling. Since it was done without cooling, at room temperature, the modules were powered on a chip-by-chip basis, one-at-a-time, and only for a short time. The continuity test was performed as each sector was mounted on the disk ring, and again upon the disk completion. It took about 5-10 minutes per sector.

An electrical test was then done after the continuity test. The purpose of the electrical test was to check that no subtle changes occurred during the mounting of the sectors on the disk ring, and to verify the stable performance of all modules. The electrical test

	Mean	Sigma
X for Front Modules	-0.1 ± 1.1 μm	12.6 ± 0.9 μm
X for Back Modules	1.1 ± 1.0 μm	11.5 ± 0.8 μm
Y for Front and Back Modules	35.3 ± 0.7 μm	11.4 ± 0.6 μm
Φ_z for Front and Back Modules	-0.029 ± 0.008 mrad	0.130 ± 0.009 mrad

Table 3: Results of the Gaussian fits to the disk survey distributions in Figure 4.

was a shorter version of the LOAD test done during sector testing, and it involved the following scans:

- MCC scan: This is a test of the MCC operation and connectivity.
- Digital functionality: This scan checks all registers (global and pixel front-end) and all buffers using digital injection to test full overflow conditions. It tests all pixels with digital injection (digital inject scan). This must do be done with nominal VDD voltage at 40 Mbps single link, 80 Mbps single link, 40 Mbps dual link, and 80 Mbps dual link.
- Analog functionality: This is the most time-consuming and complex set of scans performed with the bias voltage on. It is a sequence of operations and scans needed to certify proper analog behavior: threshold tune using internal injection to set a uniform threshold along the module, internal injection threshold scan (measures threshold and noise of each pixel using internal injection), FDAC tune and test, ToT tuning (tune the ToT response to a MIP signal for each pixel in order to have a uniform response to the collected charge in a time acceptable for operation in ATLAS; it calibrates the relationship between the measured ToT and collected charge), and the cross-talk scan to measure the cross-talk fraction and to detect bump defects resulting in increased capacitive coupling between pixels.
- Noise occupancy: This test consists of enabling one front-end chip at a time in self-trigger mode and measuring the rate of hits. Whereas pixels that generate hits at a rate greater than 1 Hz (1 kHz) are flagged as hot and are disabled in the slow (fast) mask during module and sector testing, it is not the case during disk testing. Here we only record their total number and compare these results with noise scans performed during sector testing.

A sensor bias voltage measurement was performed after the electrical scan was finished because we could not control the relevant power supply from the ATLAS TurboDAQ program. The bias voltage was ramped up to 600 V in 10 V increments to check for possible sensor damage. The current stability at different bias voltages was investigated over a period of more than 15 minutes.

7.3.3 Assembly of Disks into Endcaps

7.3.3.1 Construction

To assemble each endcap, three disks were rigidly supported by four mounts within a lightweight, octagonal, carbon composite support frame, shown in Figure 5.

Figure 6 shows a perspective cut-away view of the pixel detector. The view shows individual barrel and endcap modules, supported with their associated services on staves and disks within the octagonal support frame.

Figure 5: Carbon composite support frames.

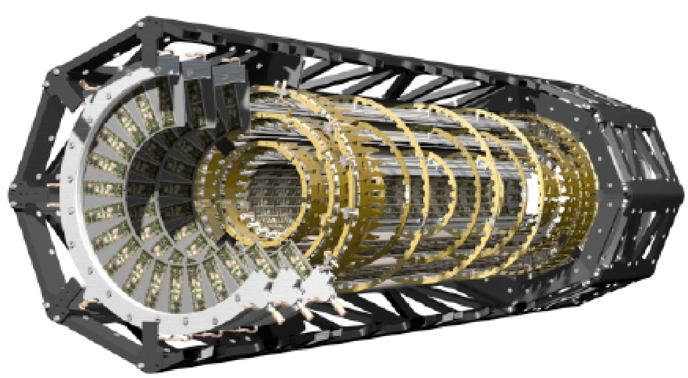

Figure 6: A perspective cut-away view of the pixel detector..

7.3.3.2 Endcap Survey

No surveys were done of the modules or sectors after the disks were assembled into an endcap, since the relevant fiducial marks were not viewable at that point.

7.3.3.3 Endcap Testing

All cooling circuits on both endcaps were leak checked down to $1-4 \times 10^{-9}$ Torr. This is the value required by the evaporative cooling system.

A connectivity test of the endcaps was performed at various stages of the integration to ensure that no modules were damaged during handling or transport. A connectivity test consists of a series of basic functionality checks performed chip-by-chip with no cooling. Each module is powered briefly and the digital, analog and bias voltages and currents are measured and compared to a set of standard values. A MCC scan is then performed as well as FE chip register/receiver tests. Each FE chip is configured to measure voltages and currents, which are compared to expected values. Finally, a short threshold scan is performed with and without bias voltage to verify that the high voltage is properly delivered to the module. The total testing time required for one endcap is two days.

A connectivity test was performed on both endcaps after loading, but before shipment to CERN.

The connectivity test was repeated after delivery of the endcaps to CERN to verify that no modules were damaged during the transport. Testing of Endcap C at CERN showed no failures on any of the modules. Endcap A showed no failures at CERN other than the three failures reported before shipment. An additional connectivity test for Endcap C was performed after integration into the Pixel Package. The test found one module with missing high voltage due to a weak bond on the module. The bond was repaired by adding silver epoxy to the high voltage hole.

Since Endcap A was used in a system test at CERN, an additional connectivity test was performed before any further integration to check for any damage to the modules during the system test or during handling in preparation for the system test. There were several modules found with intemittent HV failures. These problems were fixed by re-soldering the HV pins on the ELCO connector, by adding solder to HV wire connections, by adding silver epoxy to HV bonds, or by reinforcing glue tacks.

References

[1] A. Andreazza, V. Kostyukhin and R. Madaras, *Survey of the ATLAS Pixel Detector Components*, ATL-IP-QC-0035 (2007).

[2] ATLAS Pixel Collaboration, *ATLAS Pixel Module Electrical Test Description*, ATL-IP-QP-0144 (2004).

[3] ATLAS Pixel Collaboration, *Pixel Module Test Setup Specifications*, ATL-IP-ES-0088 (2003).

[4] ATLAS Pixel Collab., *http://pixdata.lbl.gov/surf/ambush/doc/surf-html/index.html*